VERTICAL ACCURACY EVALUATION OF DIGITAL TERRAIN MODELS CREATED BASED ON LINE-FOLLOWING DIGITIZATION OF CONTOUR MAPS

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Abstract

Digital terrain models are used in wide variety of domains and applications, of which the most important are: orthorectification of aerial and satellite images, space object modelling, passageways designing, achieving slopes exhibition maps, hydrological modeling, etc. There are several techniques for data acquisition in order to create digital terrain models, such as photogrammetry, radargrammetry, interferometry, airborne laser scanning, surveying and geodetic and cartographic digitization. By using cartographic digitization, digital terrain models are created based on the digitized contour maps on existing maps, which were brought in digital format by scanning process, this method involving low costs and being reach of a large number of users. It must therefore assess the vertical accuracy of digital terrain models created by this method. To achieve results, first were created the digital terrain models based on contour maps and points of known elevations manually digitized on plans at 1: 1000 scale and maps at 1: 25000 scale, using an interpolation grid side of 5m and spline bicubic interpolation method. Then, were determined with precision, by GNSS technology, the coordinates of 18 control points. Based on the grid nodes elevations, using the spline bicubic interpolation method, were calculated the elevations of the 18 control points and then the differences between them and those accurately obtained by GNSS technology. By performing a statistical analysis of these differences, the vertical precision of digital terrain models created from contour maps was determined.

Key words: digital terrain model, line-following digitization, contour maps, accuracy evaluation

Digital terrain models are used in wide variety of domains and applications, of which the most important are: orthorectification of aerial and satellite images, space object modelling, passageways designing, achieving slopes exhibition maps, hydrological modeling, etc. (Dana I. F., 2010). There are several techniques for data acquisition in order to create digital terrain models, such as photogrammetry, radargrammetry, interferometry, airborne laser scanning, surveying and geodetic and cartographic digitization. (Li Z. *et. al*, 2005), the digital terrain models accuracy being different for each type of data.

There are four possible approaches for assessing the height accuracy of the digital terrain models, namely: Prediction by production (procedures), Prediction by area, Evaluation by cartometric testing şi Evaluation based on control points (Li Z. *et. al*, 2005).

This paper proposes to assess the vertical accuracy of digital terrain models created by line-following digitization of contour maps, by doing a statistical analysis based on the known elevations of control points.

MATERIAL AND METHOD

Trapezoids corresponding to the study area, at 1:1000 scale, respectively 1:25000 scale, have been georeferenced, using as reference points the trapezoids corners and intersection points of the kilometric grid, with the help of TopLt software (*figure 1*).

First, corresponding to trapezoids at 1:25000 scale, the geographical coordinates of trapezoids corners and the Gauss planimetric rectangular coordinates of kilometric grid intersection points, have been transformed into planimetric rectangular Stereo -70 coordinates using the Matlab programming language.

Second, corresponding to trapezoids at 1:1000 scale, the geographical coordinates of trapezoids corners and the planimetric rectangular coordinates of kilometric grid intersection points, given in „Local Iasi” projection system, have been transformed into planimetric rectangular Stereo -70 coordinates using the GOLIATH software.

Given the fact that, in order to georeference one raster image at 1:25000 scale, 97 points have been used and to georeference one raster image at 1:1000 scale, 70 points have been used, third degree polynomial transformation method was used to optimize local accuracy (Imbroane A.M.,2012).

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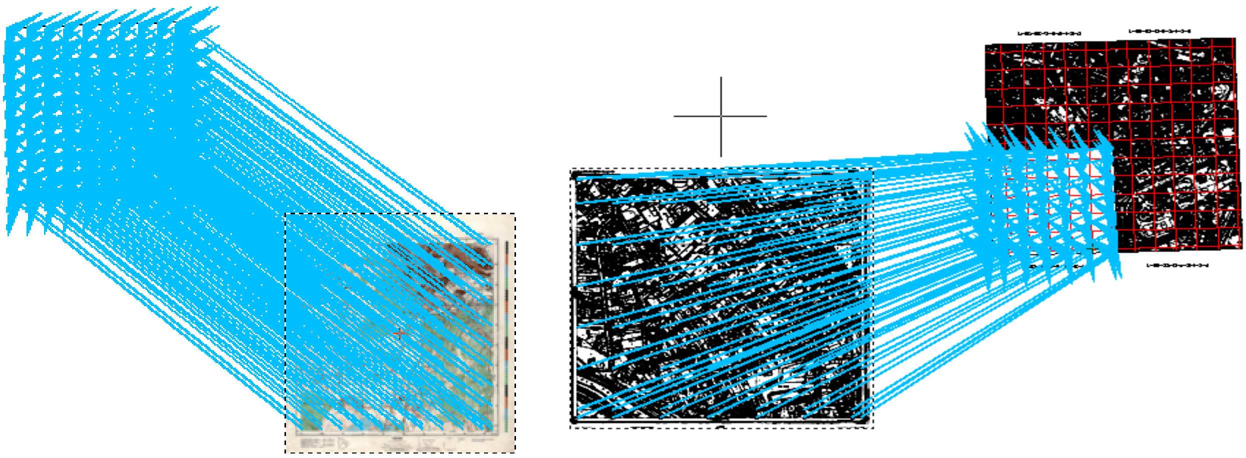


(a) (b)

Figure 1 **The process of georeferencing the maps at 1:25000 scale (a) and plans at 1:1000 scale (b) corresponding to the study area**

Then, the contour maps were digitized, on plans at 1:1000 scale namely L-35-32-C-a-2-I-2-a, L-35-32-C-a-2-I-2-b, L-35-32-C-a-2-I-2-c and L-35-32-C-a-2-I-2-d (*figure 2*), respectively on maps at 1: 25000 scale, namely L-35-32-C-a and L-35-32-A-c, corresponding to the study area, using the "*AutoCAD Map 3D 2010"* software (*figure 3*). Also, the points with known elevations, which are marked on plans and maps, were extracted.

In order to assess the vertical accuracy of surfaces created based on contour maps, digitized on maps at 1: 25000 scale and plans at 1:1000 scale, the spline bicubic interpolation method was used and 18 control points, measured using the GNSS technology.

The coordinates inventory, was obtained with the help of a program of „LISP" type, that extracts from AutoCAD, the vertices tridimensional coordinates.

The program is presented here:

```
(defun c:3dvertexes (/ doc spc ss file sel pts)
        (vl-load-com)
        (setq doc (vla-get-ActiveDocument
              (vlax-get-Acad-Object))
           spc (if (zerop (vla-get-activespace doc))
              (if (= (vla-get-mspace doc) :vlax-
       true)
               (vla-get-modelspace doc)
               (vla-get-paperspace doc))
              (vla-get-modelspace doc)))
        (if (and (setq ss (ssget '((0 .
       "*POLYLINE"))))
             (setq file
              (getfiled "Output File"
               (if *load *load "") "csv;txt" 9)))
   (progn
    (setq *load file file (open file "a"))
    (vlax-for Obj (setq sel (vla-get-
ActiveSelectionSet doc))
     (setq pts
      (vlax-list->3D-point
       (vlax-get Obj 'Coordinates)
        (cond ((eq (vla-get-ObjectName
Obj) "AcDbPolyline"))) Obj))
     (mapcar
      (function
       (lambda (x)
        (write-line
         (strcat
          (rtos (car x) 2 2) (chr 44)
           (rtos (cadr x) 2 2) (chr 44)
            (rtos (caddr x) 2 2)) file)
        (vla-addPoint spc (vlax-3D-point
x)))) pts))
    (princ
     (strcat "\n<< Points from "
      (itoa (vla-get-Count sel)) " Polylines
written to file >>"))
    (close file)
    (vla-delete sel)))
  (princ))

(defun vlax-list->3D-point (lst x Obj / oLst)
 (while lst
  (setq oLst
   (cons (list (car lst) (cadr lst)
          (if x (vla-get-Elevation Obj) (caddr
lst))) oLst)
     lst ((if x cddr cdddr) lst)))
oLst)
```

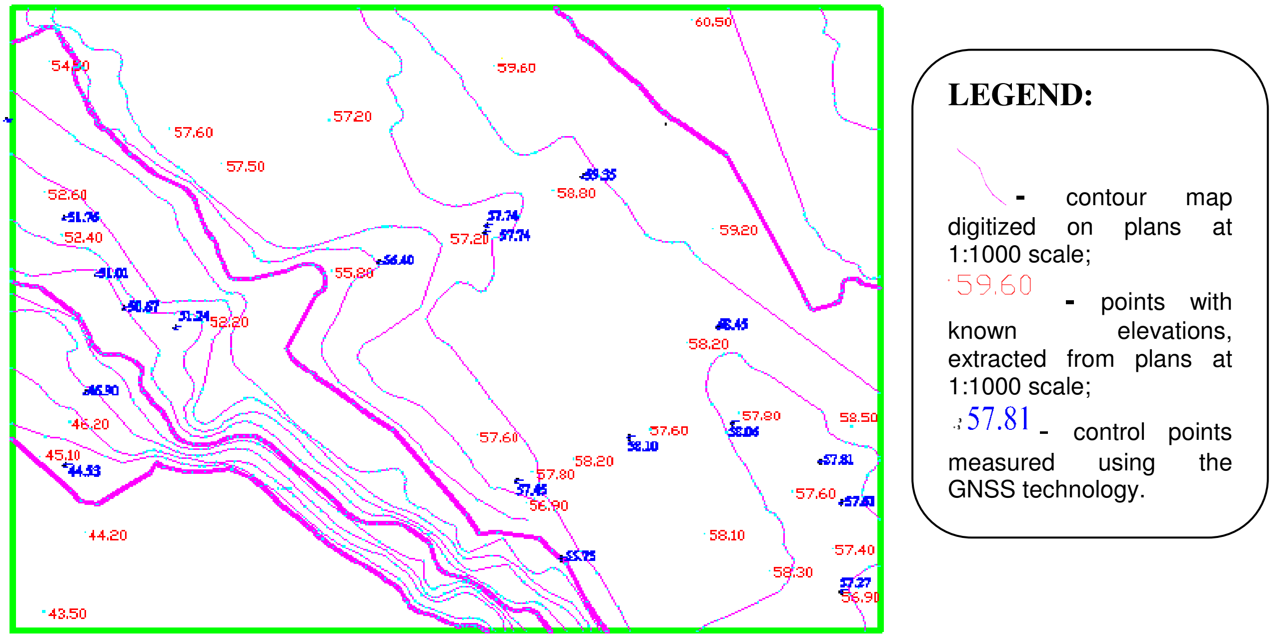


Figure 2 **The necessary data used to create the digital terrain models: contours maps and points with known elevations, digitized on plans at 1:1000 scale**

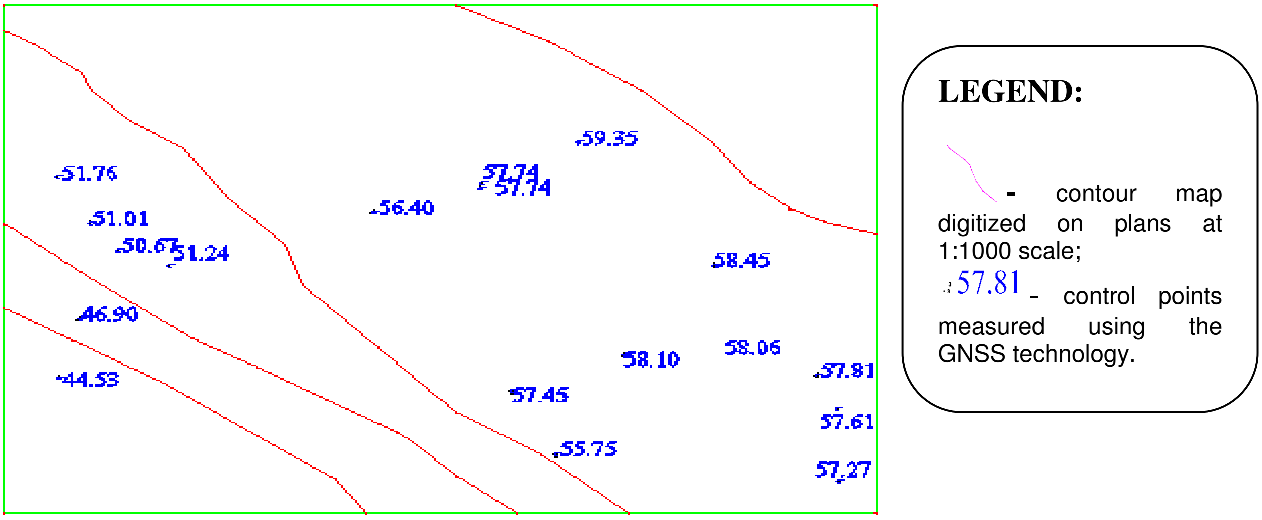


Figure 3 **The contours maps digitized on plans at 1:25000 scale used to create the digital terrain models and control points measured using the GNSS technology**

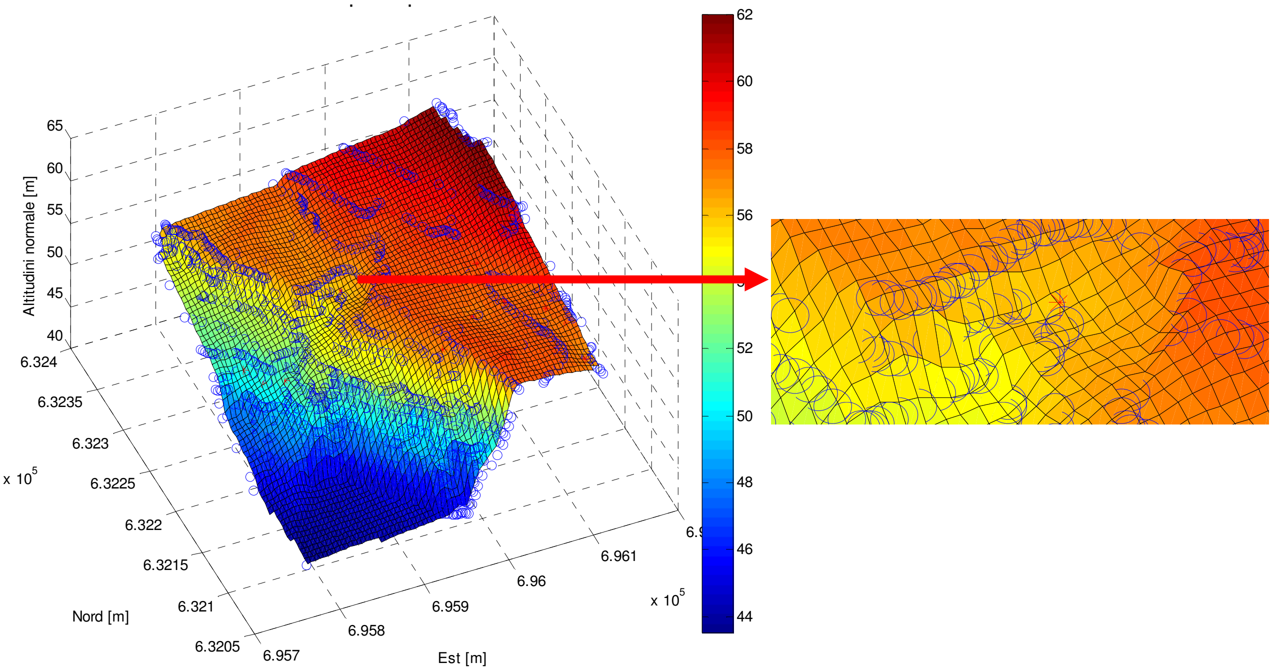
RESULTS AND DISCUSSIONS

In order to represent the 3D terrain surfaces, an interpoation grid was created using the spline bicubic interpolation method, based on the data digitized on plans at 1:1000 scale, respectively on maps at 1:25000 scale.

An important step in determining the interpolation grid is the choice of the cell size or the network step. Analyzing the specialty literature, the best way to choose the step of the cell network is iterative testing and after evaluating its results the best decision is taken. When choosing the network step is envisaged the interpolated surface shape, its degree of kneading and the source points distribution in the generated model.

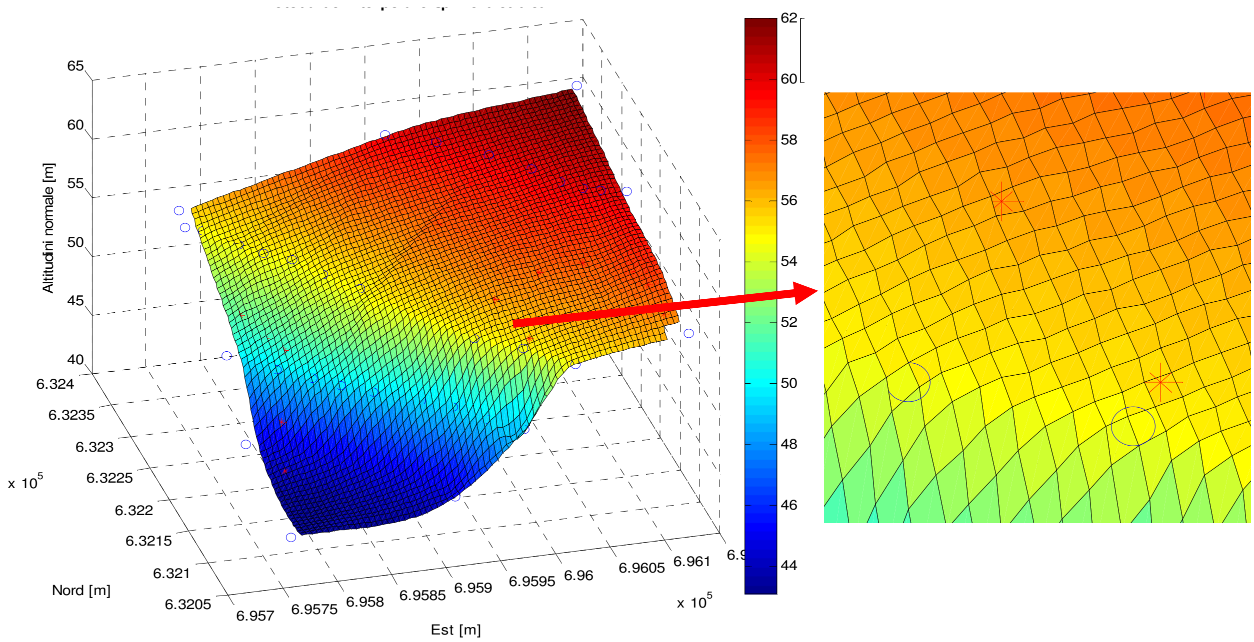
Thus, for this case study, the 5m grid step was chosen, resulting a grid of 58×78 lines and 4524 nodes.

Surfaces resulted after the interpolation process by spline bicubic interpolation method, with the grid step of 5 m, of points belonging to the contour maps digitized on plans at 1:1000 scale and maps at 1:25000 scale, are presented in *figure 4* and *figure 5*, where the blue points represents the polylines vertices and also the points with known elevations and the red points represents the control points.



(a) **(b)**

Figure 4 **(a) The surface corresponding to the study area, obtained by spline bicubic interpolation method, with 5 m grid size, based on points that belong to contour maps digitized on plans at 1:1000 scale and (b) detail**



(a) **(b)**

Figure 5 **The surface corresponding to the study area, obtained by spline bicubic interpolation method, with 5 m grid size, based on points that belong to contour maps digitized on maps at 1:25000 scale and (b) detail**

In order to assess the vertical accuracy of the surfaces created based on contour maps, the standard deviation for each control point was calculated with the following equation:

$$\sqrt{\sum_{i=1}^{n} \frac{(x-\bar{x})^2}{n}} \qquad (1)$$

where $\bar{x}$ is the values average and n is the values total number.

The deviations average in absolute value from the mean was calculated with the equation:

$$\frac{1}{n}\sum_{i=1}^{n}\left|x-\bar{x}\right| \qquad (2)$$

where $\bar{x}$ is the values average and *n* is the values total number.

Differences obtained between the normal altitudes of the 18 control points, measured by GNSS technology and those obtained by interpolation, based on contour maps digitized on plans at 1:1000 scale and maps at 1:25000 scale, are presented in *table 1*.

The differences distribution histogram were calculated in Matlab and are presented in *Figure 6.*

Table1

Differences obtained between the normal altitudes of the 18 control points, measured by GNSS technology and those obtained by interpolation, based on contour maps digitized on plans at 1:1000 scale and maps at 1:25000 scale

Differences between normal altitudes calculated in control points							
Plans at 1:1000 scale				Maps at 1:25000 scale			
1	0.142	10	-0.212	1	0.103	10	0.293
2	-0.191	11	-0.171	2	-0.919	11	-0.300
3	0.027	12	0.404	3	-0.847	12	-0.264
4	0.121	13	-0.575	4	0.001	13	-0.006
5	0.374	**14**	**-0.871**	5	0.692	14	-0.984
6	**0.889**	**15**	**-0.840**	6	0.581	15	0.531
7	0.103	16	-0.280	**7**	**1.394**	16	0.573
8	0.149	17	0.150	8	-0.521	17	-0.854
9	0.490	**18**	**-0.843**	9	0.103	18	-0.699

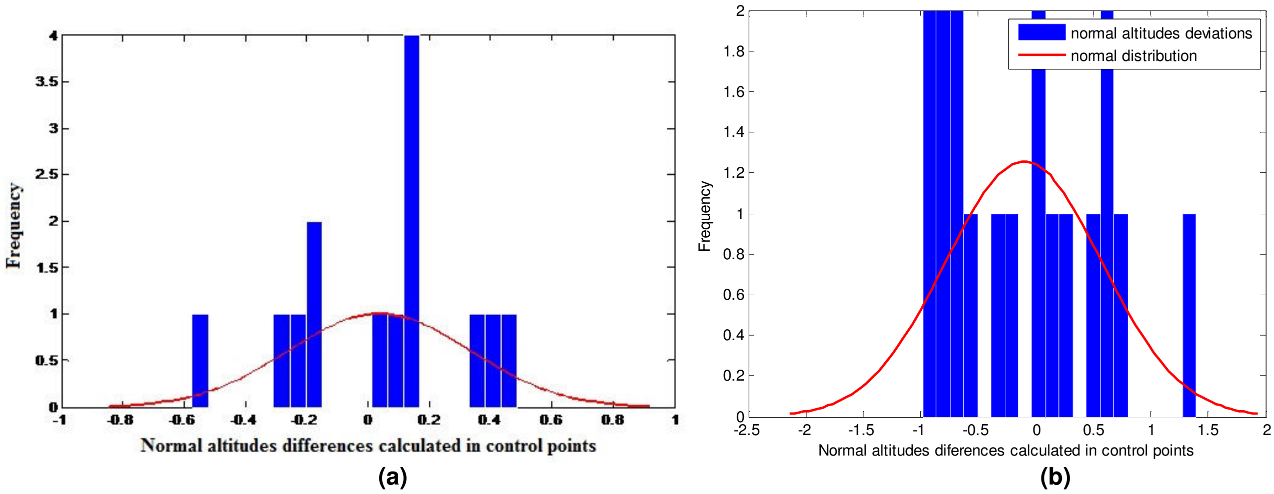


Figure 6 **The differences distribution histograms, calculated between the normal altitudes of the 18 control points, measured by GNSS technology and those obtained by interpolation, based on contour maps digitized on plans at 1:1000 scale (a) and maps at 1:25000 scale (b)**

We can observe that, in the case of the differences calculated based on plans at 1:1000 scale, respectively on maps at 1:25000 scale, for four control points, respectively 1 control point, from the total of 18 control points, differences deviate greatly from the average value. This may be due to the fact that errors might have occurred in the digitization process, given that the study area is the central area of Iasi, an area dominated by buildings (Li Z. *et. al*, 2005).

The statistical results obtained for the data sets resulted by contour maps digitization on plans at 1:1 000 scale, repectively on maps at 1:25000 scale, using a 5 m grid step and spline bicubic interpolation method, are presented in *table 2* (Chirila C. *et al*., 2013):

Table 2

Statistical analysis of the data sets obtained by contour maps digitization on plans at 1:1 000 scale, repectively on maps at 1:25000 scale

Scara	Control points	Standard deviation (cm)	Maximum value of the deviation (cm)	Deviations average in absolute value from the mean (cm)
1:1000	18	0.47	0.89	0.39
	14	0.28	0.57	0.23
1:25000	18	0.66	1.39	0.57
	14	0.57	0.98	0.51

CONCLUSIONS

The vertical accuracy calculation of digital terrain models created based online-following digitizations of contour maps, is done by testing a sufficient number of control points uniformly distributed on the considered study area.

Data sets were statistically analyzed by the correlation between normal altitudes of control points determined by GNSS technology and those calculated by interpolation.

In the case of the data set obtained by contour maps digitization on plans at 1:1000 scale, the standard deviation was 28 cm.

In the case of the data set obtained by contour maps digitization on maps at 1:25000 scale, the standard deviation was 57 cm.

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